

CORAL REEF WATCH 2002

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ABSTRACT

The National Oceanic and Atmospheric Administration's new Coral Reef Watch (CRW) program, led out of its National Environmental Satellite, Data, and Information Service (NESDIS) and Oceanic and Atmospheric Research (OAR) offices will strive to fully utilize NOAA coral resources to monitor and predict changes in coral reef ecosystems worldwide. CRW inaugurated its first Coral Reef Early Warning System (CREWS) station in 2001 at "Rainbow Gardens," Lee Stocking Island, Great Exuma, Bahamas, with the installation of its first of 20 new in situ monitoring stations slated for many domestic reefs during this decade. A major objective is to discern the relationship between the magnitude and persistence of anomalously high sea surface temperatures in coral reef areas and coral reef bleaching and mortality. By coordinating both in situ point observations with the overview provided through satellite imagery this program is designed to actively support coral reef managers and researchers through near real-time Web-access to coral reef environmental data and coral bleaching alerts.

This paper is part in a series of papers resulting from a scientific workshop held at the Caribbean Marine Research Center (CMRC, December 2001) to evaluate the importance of back reef systems for supporting biodiversity and productivity of marine ecosystems. Coral reefs are one of the most diverse ecosystems in the World, supporting essential coastal fisheries, offering potential medicines, protecting coasts from erosion, and supporting coastal tourism industries.

Over the past few years, anomalously warm sea surface temperatures have led to increased incidence of coral reef bleaching around the globe (Goreau et al., 1998; Goreau et al., 2000; Wilkinson et al., 2000; Wellington et al., 2001b), such as that occurred in early 2001 at Ningaloo, South Indian Ocean (Fig. 1). This stress compounds stresses already incurred via natural factors such as hurricanes and our changing climate and a myriad of factors associated with detrimental human activities, such as overfishing, anchor damage, sediment and nutrient run-off, and unregulated tourism. Increased deterioration of coral ecosystems is of major concern worldwide as human impacts undoubtedly are playing an increasing role.

Recognizing the need to protect these fragile ecosystems, in 1998 the U.S. federal government called for increased research and monitoring of coral reefs for improved management by establishing the multi-agency U.S. Coral Reef Task Force. In 1999, NESDIS sponsored a Workshop at the East West Center in Honolulu, Hawaii: "International Workshop on the Use of Remote Sensing Tools for Mapping and Monitoring Coral Reef." The fortuitous timing of these two events during and immediately following the major bleaching event brought on by the most recent El Niño (1997–98) assisted in galvanizing much of the coral reef community in recognizing both the benefits of the new Internet-dependent society and the often basin-wide orchestration of many of these bleaching events.

As early as 1995, NESDIS began producing worldwide, web-accessible, satellite-derived, sea surface temperature products to monitor for potential coral reef bleaching (Strong et al., 1997). Additionally, NESDIS has been providing technical support for

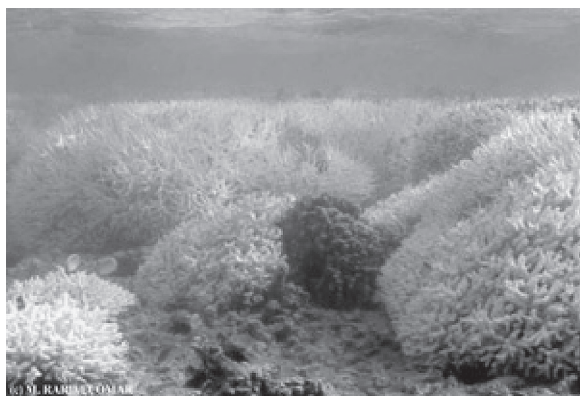


Figure 1. Bleaching at Ningaloo Reef, South Indian Ocean, February 2001.

coral reef mapping efforts, developing a robust and comprehensive international coral reef data management system, using paleo-climate records to describe the coral reef environment in the past (>100 yrs), and building interagency and international collaborations in coral monitoring and research. Simultaneously, OAR's Atlantic Oceanographic and Meteorological Laboratory (AOML) had been developing the Coral Reef Early Warning System (CREWS), an integration of meteorological and oceanographic instrumented arrays (buoys and dynamic pylons) with artificial intelligence software. These CREWS stations are being deployed as coral reef environmental monitoring stations to monitor for conditions theoretically conducive to coral reef bleaching (e.g., high sea temperature alone, high temperature plus high irradiance; see Hendee et al., 2001), and provide long-term data sets for other coral reef ecosystem modeling and for Marine Park Area (MPA) decision support. The CREWS concept grew out of prototyping and experimentation under the Florida Institute of Oceanography and NOAA's similarly instrumented-array SEAKEYS program, developed in the early 1990s for the Florida Keys National Marine Sanctuary (Ogden et al., 1994).

CORAL REEF WATCH (CRW)

In an effort to expand NOAA's coral reef monitoring and bleaching alert capabilities NESDIS and OAR joined their complimentary coral activities under the Coral Reef Watch initiative in 2000. CREWS temporally intensive sea temperature (and other) data serve to validate NESDIS satellite-derived spatially intensive sea surface temperature monitoring products, while NESDIS satellite products extend coral reef bleaching monitoring to larger spatial scales and remote locations. Within NESDIS and within OAR, CRW maximizes coral reef resources by joining the existing coral reef strengths under a coordinated program.

CRW seeks to fully utilize space-based sea surface temperature (SST) observations combined with CREWS in-water derived data to continually monitor for early indications of thermally induced coral bleaching worldwide. As part of CRW, the NESDIS satellite coral bleaching monitoring program has been using 50-km, twice-weekly, night-time-only satellite advanced very high resolution radiometer (AVHRR) SST to derive its core coral bleaching "early warning" products, bleaching HotSpot anomaly charts, and bleaching Degree Heating Weeks (DHW) charts as indices of coral reef bleaching related thermal stress (Strong et al., 1999, Toscano et al., 1999). The "HotSpot" technique

is proving to be highly successful in providing early warnings of thermally induced coral reef bleaching to the coral reef community (Goreau et al., 2000, Wellington et al., 2001a). The coral bleaching HotSpot is a type of SST anomaly showing positive anomaly (potential thermal stress) compared to a "static" bleaching threshold SST climatology. A satellite maximum monthly mean SST climatology derived from the satellite AVHRR SSTs over a period of 1985–1993 has been used as the threshold climatology, which is static in time but varies in space (Strong et al., 1997). Only the positive anomalies are calculated and highlighted in the HotSpot charts as the indices of coral bleaching inducing thermal stress. The DHW represents the accumulation of HotSpots during a previous 12 wk time period and the HotSpot anomalies have to be at least $+1^{\circ}\text{C}$ to be accumulated. One DHW is equivalent to 1 wk of HotSpot levels staying at 1°C or 0.5 wk of HotSpot levels at 2°C , etc. To assess the accuracy of the HotSpot technology, comparing the satellite SST with hourly measured in situ water temperature observations at the developing CREWS network should be a necessary first assessment step.

In the Caribbean alone, considerable bleaching variability has been seen over the past decade from episodes of high SSTs. At NESDIS we are actively bringing on-line newly-improved Pathfinder (AVHRR) SST data with higher resolution SSTs from what has been available operationally (mapping at 9 versus 50 km resolution) and more consistently derived observations, being compared methodically against point-source information from drifting buoy SSTs (Kilpatrick et al., 2001).

HotSpot Charts, highlighting regions of possible thermally induced coral reef bleaching, are shown for the Caribbean in Figure 2. HotSpots are shown as an anomaly above the expected maximum climatological SST for the entire year (Toscano et al., 2001). Yellow/orange indicates bleaching potential and white indicates no bleaching potential – blue/purple indicates levels just below critical. Numbers correspond to representative reef locations shown in Table 1. Over the years of derived Pathfinder satellite SST observations, 1985–1998, 1985 (Fig. 2, top) was a relatively cool year, while 1998 (Fig. 2, bottom) was relatively warm. The bar graph in Figure 3 highlights the variability in the number of the 12 representative reef sites (above) that appear to have experienced sea surface temperatures at sufficient levels (at least 1°C above climatological maximum SST for the year) to cause coral reef bleaching during each year from 1985–1998.

At the Lee Stocking Island CREWS station, R/V KRISTINA (buoy), shown on station in Figure 4, a critical part of the effort is the local maintenance and calibration of the sea temperature sensor to ensure quality data; these data can then be automatically compared with satellite monitored temperatures and thus provide near real-time feedback on the accuracy of the satellite-monitored temperatures. The CREWS buoy R/V KRISTINA routinely measures and transmits directly via satellite the following parameters (<http://coral.aoml.noaa.gov/crw/crw_data_bahamas_72.html>): Barometric pressure; air temperature; water temperature; tide; wind (speed, gust, direction); conductivity; salinity; photo-synthetically active radiation – PAR (Surface, 1 m); and UVB (Surface, 1 m).

The staff at Lee Stocking Island maintaining the station also give critical feedback on the presence and progress of coral bleaching and thus validate coral bleaching predictions made by both satellite HotSpot anomalies and in situ CREWS information products. Buoy R/V KRISTINA is the first of ~20 CREWS stations to be deployed throughout U.S. domestic reefs. Its location is near Rainbow Gardens Reef where the CMRC has maintained in situ data loggers. These data supply another source of high temporal resolution sea temperature data to further compare with the more spatially comprehensive 50-km satellite SSTs that are derived from nearby pixels at the relatively shallow Great

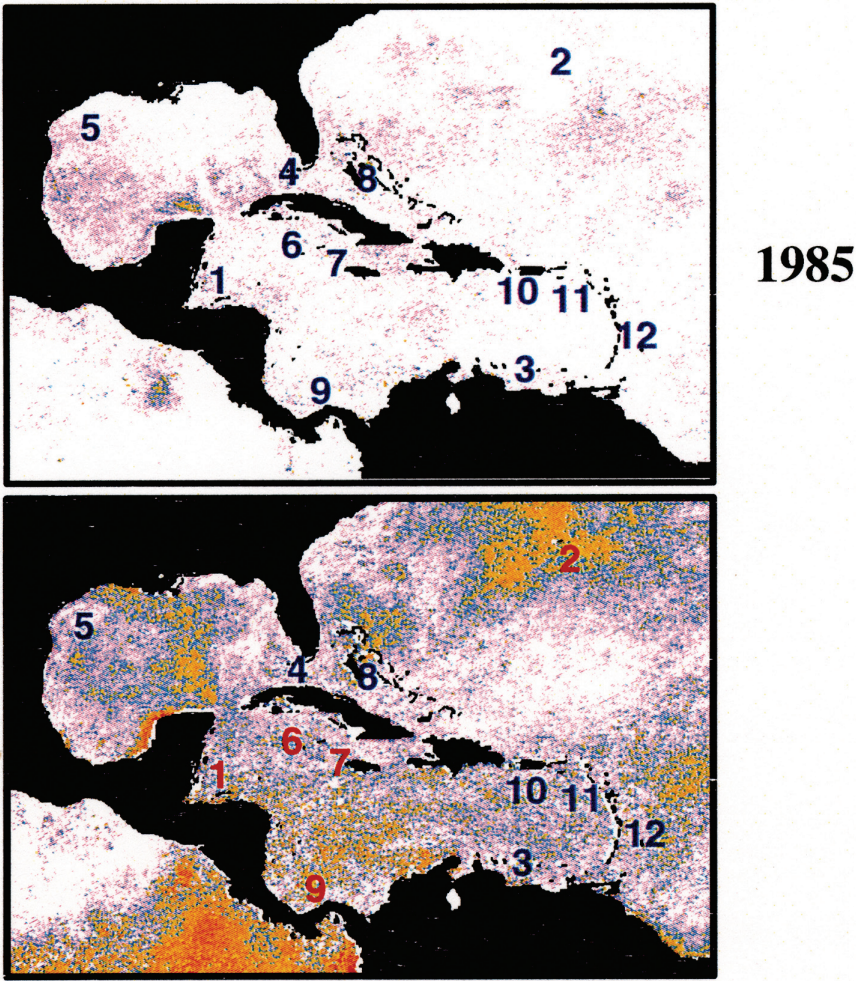


Figure 2. 1985 and 1998 Caribbean Pathfinder SST Annual Composite HotSpot Charts – at sites 1,2,6,7,9 HotSpot levels (white = warmest) were reached in 1998.

Bahama Bank (west) and much deeper Exuma Sound (east). During summer, 2001, buoy R/V KRISTINA successfully transmitted via satellite its in situ temperature measurements, which showed good agreement with our satellite SSTs (Fig. 5) but averaged nearly a constant 1°C cooler than the SST loggers at Rainbow Gardens Reef. This was presumed to be due to the increased flow and mixing at the site of R/V KRISTINA compared with the shallower site of Rainbow Gardens Reef nearly 1 mi to the north. It will be interesting to see if this difference reverses during the winter months. Logger data helped to validate and interpret the satellite SST and CREWS station readings.

Table 1. Reef locations located in Fig. 2.

Representative reef locations
Belize (1)
Bermuda (2)
Bonaire (3)
Dry Tortugas, Florida (4)
Flower Garden, Texas (5)
Grand Cayman (6)
Jamaica (7)
Lee Stocking Island (8)
Panama – Atlantic (9)
Puerto Rico (10)
St. Croix, U.S.V.I. (11)
St. Lucia (12)

A CASE STUDY — RAINBOW GARDENS, LEE STOCKING ISLAND

This particular study attempted to compare the new CREWS buoy (R/V KRISTINA) with existing in situ CMRC data from Rainbow Gardens Reef to make this new data source, nearly 1 mi from the CMRC site, comparable (if possible) to previous historical data. The study also attempted to relate the new data stream from satellite information somewhat farther from shore to both the CREWS buoy and the CMRC data logger. Satellite SST time series extracted from NOAA's global 50-km nighttime SST datasets at the two closest pixel locations (centered at 23°30'N, 76°30'W, noted as SW pixel and 24°N, 76°W, as NE pixel) at Lee Stocking Island (LSI), Bahamas were used to compare with the CMRC in situ logger water temperature time-series at Rainbow Gardens Reef (23°47.78'N, 76°08.78'W). The two SST pixels are the pixels closest to the Rainbow Gardens logger, one over the shallow Great Bahama Bank to the west and one over a considerably deeper Exuma Sound to the east. The Rainbow Gardens logger is located in shallow water (seawater depth of 4 m) close to a small island (Iguana Cay) and adjacent to an active tidal channel between the Bank and Sound. The temperature sensor is 0.3 m above the bottom. The logger is approximately in the middle of the two non-land contaminated satellite data pixel centers.

The polar-orbiting satellite nighttime passes over the Rainbow Gardens Reef were usually between midnight and before sunrise local time. The logger water temperature observations are available at hourly intervals. For the purpose of comparison, the same value of a composite twice-weekly nighttime SST analysis at a pixel was applied as the SST daily value during the twice-weekly period. This "daily" SST was then compared with the daily mean (0:00–23:00 LT) and also nighttime mean (18:00–05:00 LT) of the Rainbow Gardens logger temperature over the period: September 2000 through July 2001. The results are shown in Figure 6.

The mean differences between the SST at the SW pixel and the CMRC in situ logger temperature were -0.10°C and -0.02°C (STD: 0.63°C and 0.72°C) for in situ daily mean and nighttime mean, respectively, and the NE pixel, -0.26°C and -0.13°C (STD: 0.70°C and 0.76°C). The comparison between the mean SST of the two pixels and the

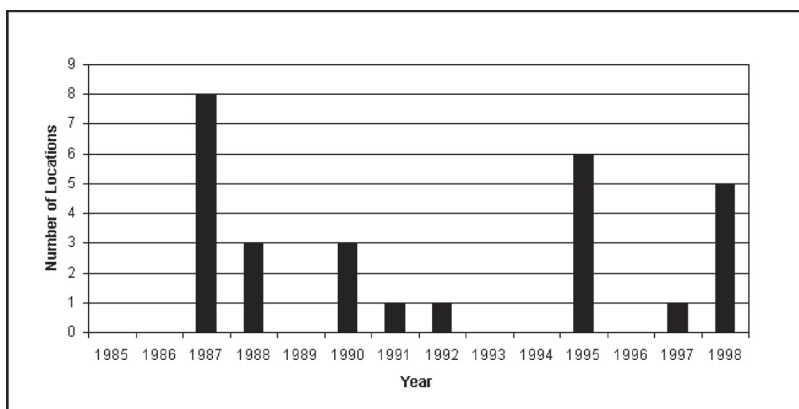


Figure 3. Bar chart frequency of reef locations in Table 1 coinciding with HotSpot data.

logger temperature showed a mean difference of -0.18°C and -0.06°C (STD: 0.60°C and 0.68°C) for in situ daily mean and nighttime mean, respectively.

The visual examination of the difference between the SST at these two adjacent pixels and CMRC logger temperature found that at each pixel the difference periodically increases and decreases and the difference is usually out-of-phase at the two pixels. This suggests that the phase difference may be caused by the change in direction of the current in the tidal channel passing by the Rainbow Gardens Reef logger. Physical characteristics of the shallow bank and the deep sound are significantly different. With this assumption, two new SST time series were constructed by choosing the SST value, for each day, from one of the two pixels with the smaller temperature difference to the logger temperature. One time series was to best fit the daily in situ mean temperature and another daily nighttime in situ mean temperature. The resulting comparisons showed a decrease in the mean difference and standard deviation: -0.11°C with STD of 0.50°C and -0.02°C with STD of 0.57°C for daily mean and nighttime mean in situ values, respectively. From our inspection at this LSI site, the scatter plots showed that the best-fit SST time series have the least scatter. But all scatter plots showed that satellite-derived SSTs are 'lower' than in situ temperature at the high temperature end and "higher" at the low temperature end. We will be examining the hypothesis that this might be attributed to land (island)-sea temperature differences as we continue to compare these values over the next few months.

The comparison between the monthly means derived from the SST and in situ Rainbow Gardens Reef logger showed that the mean difference was -0.10°C with STD of 0.28°C , 0.03°C with STD of 0.36°C for daily mean and nighttime mean in situ values, respectively, for the SW pixel and -0.23°C with STD of 0.4°C and -0.11°C with STD of 0.39°C for NE pixels; -0.17°C with STD of 0.26°C and -0.04°C with STD of 0.29°C for mean of the two pixels; and -0.1°C with STD of 0.2°C and -0.005°C with 0.24°C for the best-fit SST values.

The comparison between the weekly means derived from the SST and CMRC logger temperature showed that the mean difference was -0.10°C with STD of 0.42°C , 0.02°C with STD of 0.49°C for daily mean and nighttime mean, respectively, for the SW pixel; -0.25°C with STD of 0.54°C and -0.13°C with STD of 0.56°C for the NE pixel; -0.18°C with STD of 0.40°C and -0.06°C with STD of 0.46°C for mean of the two pixels; and -0.11°C with STD of 0.29°C and -0.015°C with 0.35°C for the best-fit pixel.

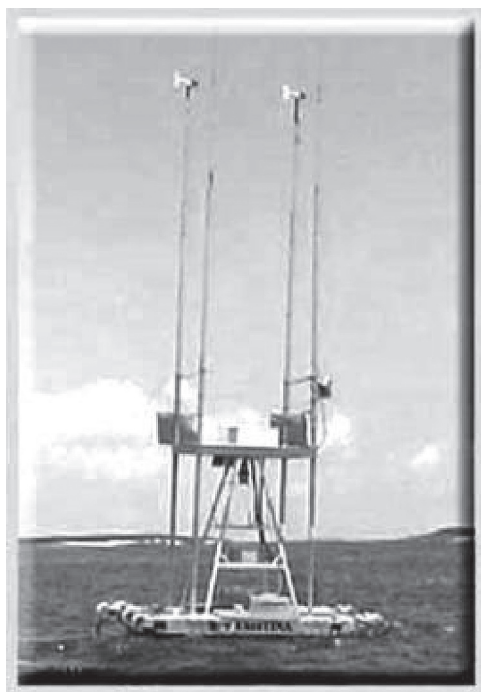


Figure 4. Lee Stocking Island CREWS buoy: R/V KRISTINA

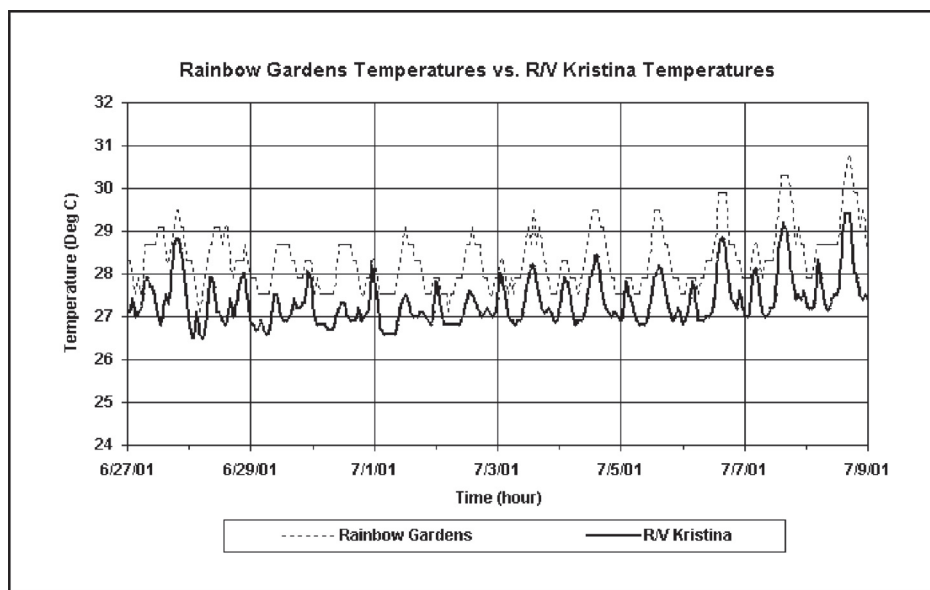


Figure 5. 12 d of SSTs from Rainbow Garden logger and R/V KRISTINA: 27 June–8 July 2001.

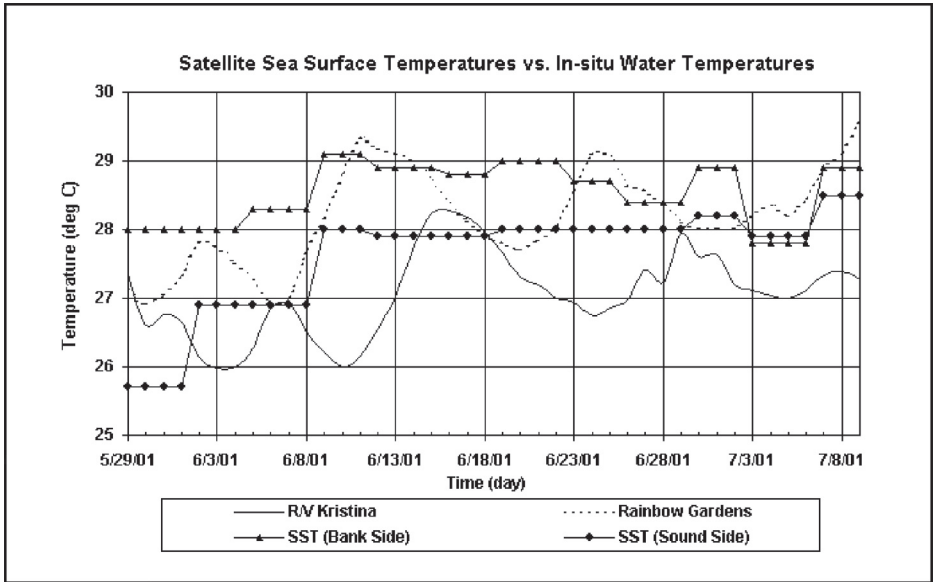


Figure 6. Daily comparisons of SST from: R/V KRISTINA, Rainbow Gardens logger and satellite pixels to the SW (Bank) and NE (Sound) of Kristina location: 29 May–8 July 2001.

The results from this initial CREWS-site data logger comparison lead us to conclude that the 50-km satellite nighttime SST analysis is providing a very good match with the in situ temperature observation even though it is at a depth of nearly 4 m. Occasionally we noted the absence of an SST observation due to cloud cover. Sub-resolution cloud elements may decrease the satellite’s SST accuracy. Our findings also suggest that the diurnal vertical mixing due primarily to high tidal velocities at Rainbow Gardens Reef were active over the comparison period. The SST algorithm aims to calibrate its measured temperature to be representative to a 1-m bulk water temperature. From our brief study it would appear that the 50-km nighttime satellite SST is providing water temperatures for the shallow water areas, typical for LSI reefs, at the required accuracy level. The extreme 2–3° temperature swings observed during the period provide useful water temperature information representative alternately of both the Bank and the Sound. However, the SSTs at both pixels are needed to give more accurate monitoring of water temperature at the Rainbow Gardens Reef. More observation and research are needed to determine which one at what time is suitable for monitoring the water temperature at the location.

BENEFITS

For coral reef managers, CRW near real-time Web-based monitoring products permit immediacy in response to changing ecosystem character, which has allowed for improved regulation of access to the reefs in question. By maintaining a more constant vigilance and carefully coordinating with reef (MPA) managers having oversight of the threatened jurisdictions, we stand an increased likelihood of being able to reduce stress resulting from fishing and recreational activities during periods of high stress, e.g., high

water temperatures. If we are successful, although coral mortality cannot be completely stopped, stresses can be minimized and recovery maximized through improved awareness and management practices. CRW data and products have begun to deliver the tools necessary to alert managers and researchers, for the first time, to be responsive as soon as adverse environmental conditions begin to develop. Their on-site feedback not only acquires initial bleaching information first hand but contributes greatly to our understanding of coral bleaching phenomena. Moreover, the accumulation of both satellite and in situ CRW long-term data sets will aid in our understanding of our coral reefs' response to climate change as well as coral reef ecosystem function.

PLANS

In 2002, NESDIS and OAR will seek to improve spatial coverage, reliability, quality, and accessibility of CRW data and products by:

1. Expanding the network of coral reef environmental monitoring stations to the U.S. Virgin Islands and American Samoa
2. Adding pollutant indicator sensors to existing environmental monitoring stations to provide a more complete set of environmental parameters for monitoring and modeling coral reef ecosystems
3. Improving national and international collaboration and information exchange in order to validate monitoring data and bleaching alert products as well as better understand the coral bleaching phenomenon
4. Securing technical support for satellite near real-time coral reef bleaching and monitoring products to ensure their availability during critical seasons
5. Increasing the spatial resolution of satellite monitoring and bleaching alert products, thus improving applicability and relevance to smaller scale ecosystems
6. Performing temporal assessments of coral reef bleaching using high-resolution satellite data
7. Providing automated bleaching event maps in user-friendly formats (e.g., Geographic Information System)
8. Extending SST records using the coral paleo-climate proxy record, thereby promoting an understanding of coral's response to environmental conditions in the past
9. Continuing development of the NOAA international Coral Reef Information System (CoRIS) that enhances access to NOAA, national, and international coral reef data and information worldwide.

SUMMARY

The Coral Reef Watch 2002 Project embodies a coordinated NESDIS and OAR coral monitoring and bleaching research program that responds to a need for improved understanding of coral reef ecosystems and fulfills NOAA's mission to Sustain Healthy Coasts. The planned 2002 activities fully exploit NESDIS and OAR expertise in data management, satellite mapping and monitoring, while hopefully encouraging diverse partnerships and communication.

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